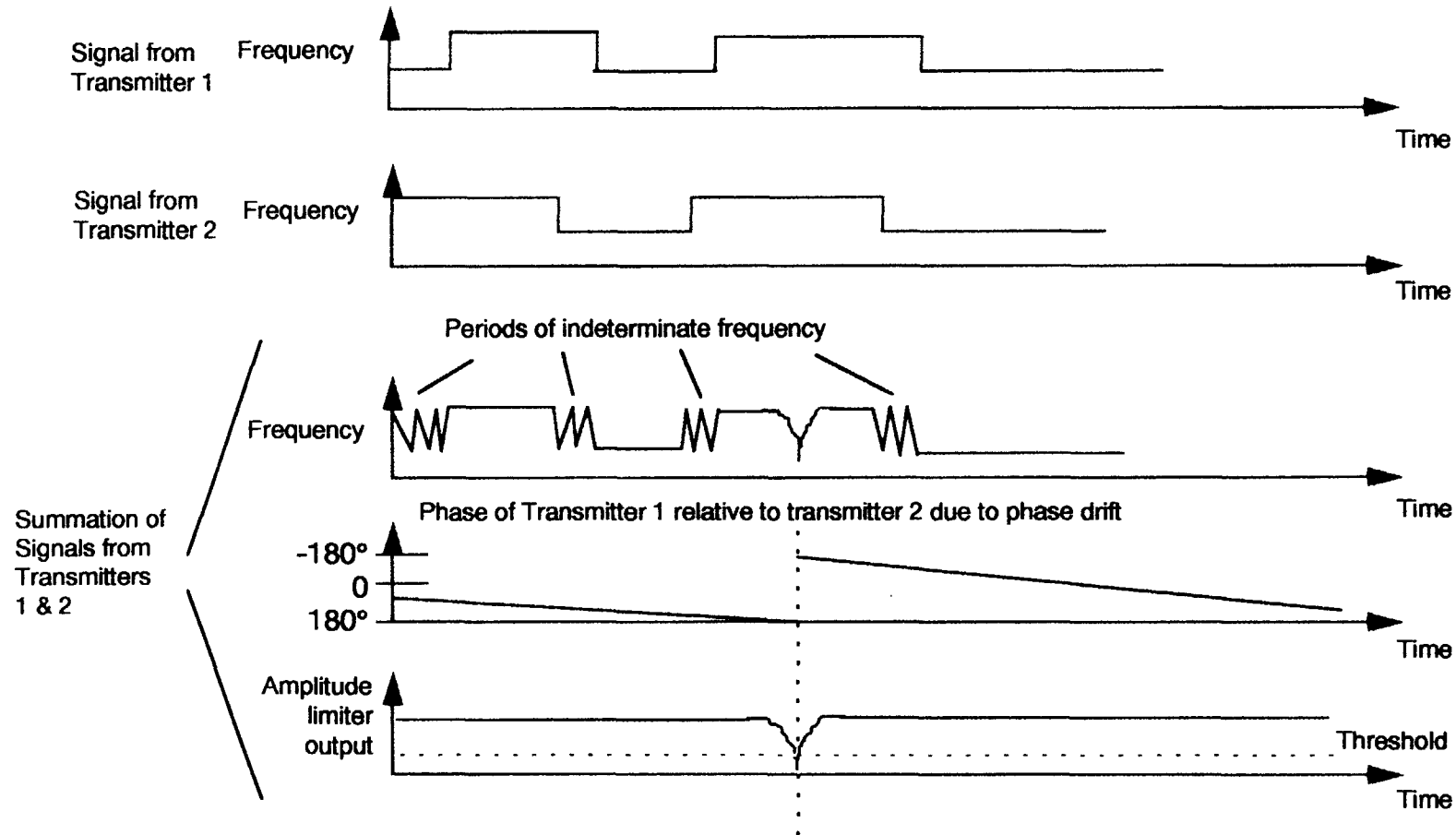


Modulation Waveforms



Approach

- ❑ Field measurements in simulcast environment
- ❑ 930-931 MHz frequency band
- ❑ Minimize hardware delays - use GPS
- ❑ Make measurements for various data rates and bandwidths:

Data Rate (kbaud)

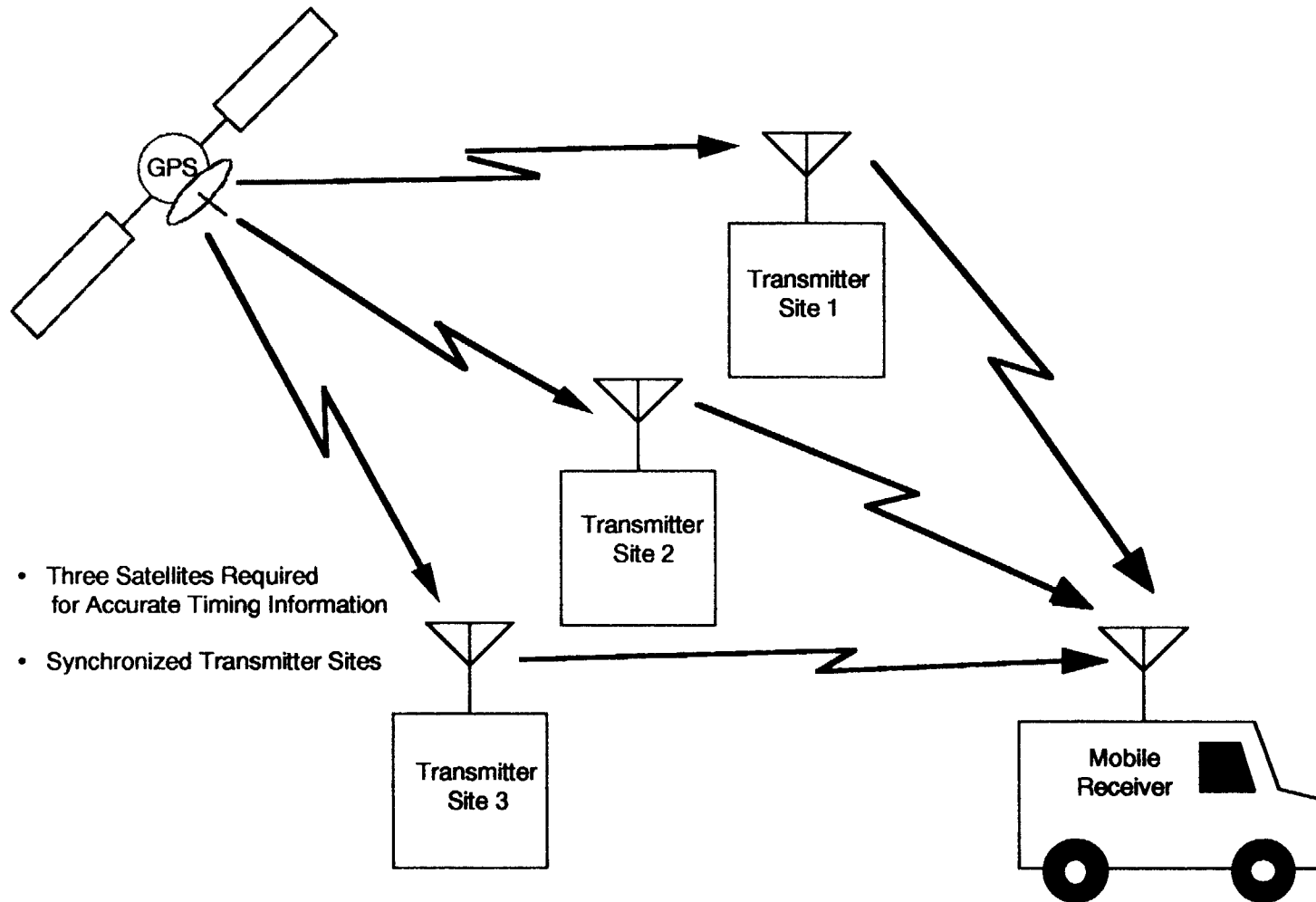
1.2, 2.4, 3.2, 6.4
12.8

Bandwidth (kHz)

25
50

- ❑ Measurements include relative delay, relative signal strength, relative frequency offset and Bit Error Rate
-

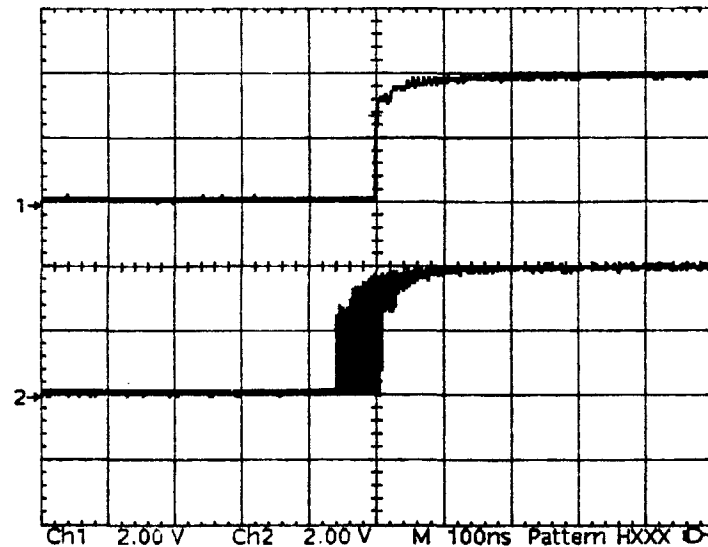
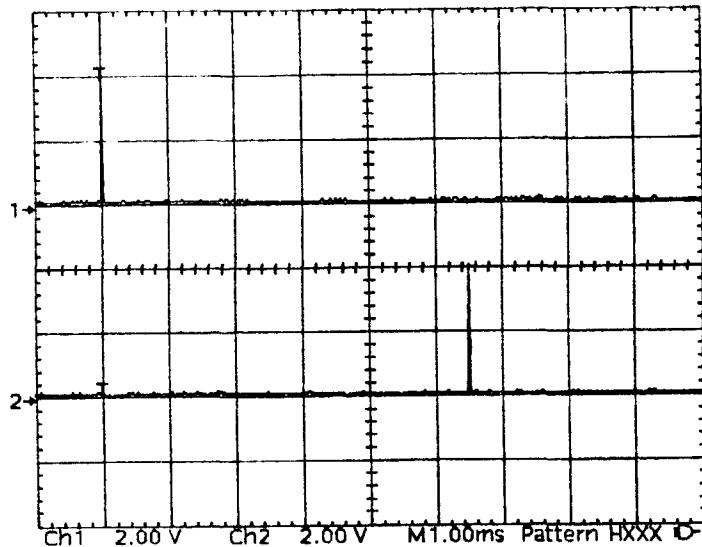
Simulcast Paging System Test



Methodology

GPS 1pps Synchronization

- ❑ Synchronization of transmit signals using GPS to within < 1 microsecond
- ❑ Pseudo random data sources



Methodology (Cont'd)

Best Server Coverage

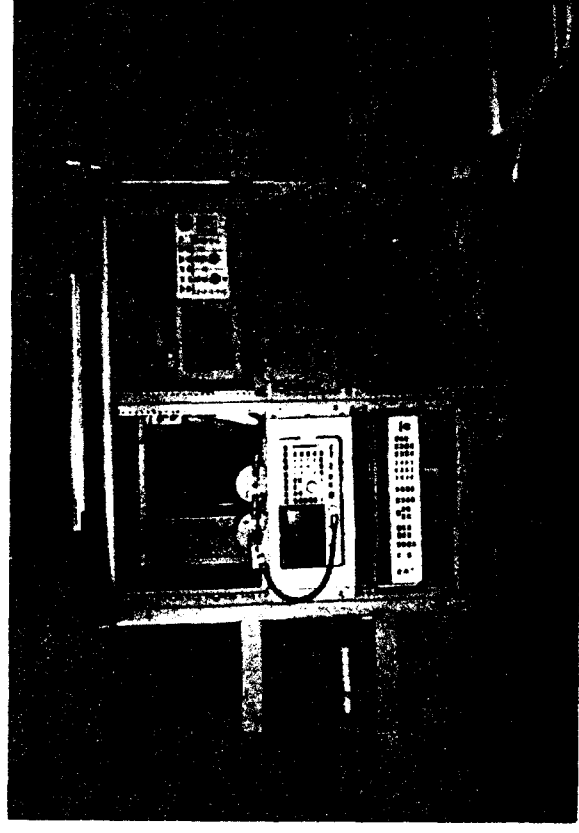
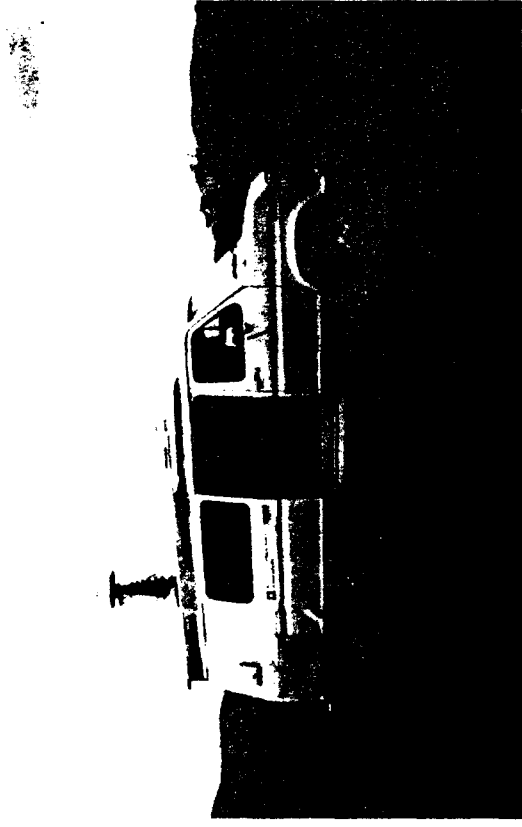
- ❑ Two existing PacTel Paging sites used



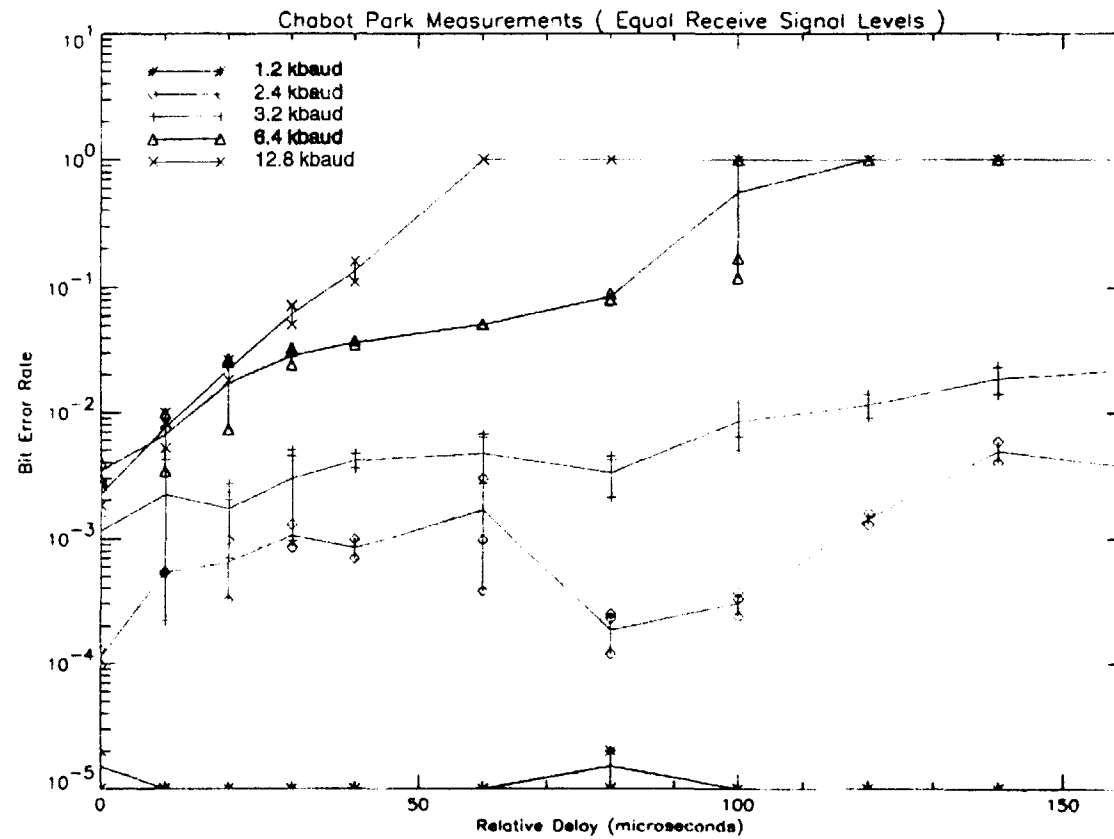
Methodology (Cont'd)

- ❑ Receive equipment placed in mobile van
 - ❑ Receive vehicle also equipped with GPS to measure relative delays
 - ❑ Measurements
 - Equal receive signal strength
 - Stationary
 - Site chosen to avoid temporal fades
-

Receiver Equipment and Vehicle



Results



Measured BER vs. Relative Delay

Conclusions

- ❑ Synchronization of transmit signals to within < 1 microsecond using GPS
 - ❑ Present paging equipment operating at 1.2 kbaud provides a robust simulcast paging system under the worst case field measurement conditions
 - ❑ The results suggest that an upper limit on data rate over the air is approximately 3.2 kbaud. This assumes an appropriate coding scheme
 - ❑ Phasing of the frequency references causes a finite BER at zero delay
 - ❑ For the test equipment used, approximately 10 dB is required to make the detection process independent of delay for significant relative delays, 50% of bit duration
-

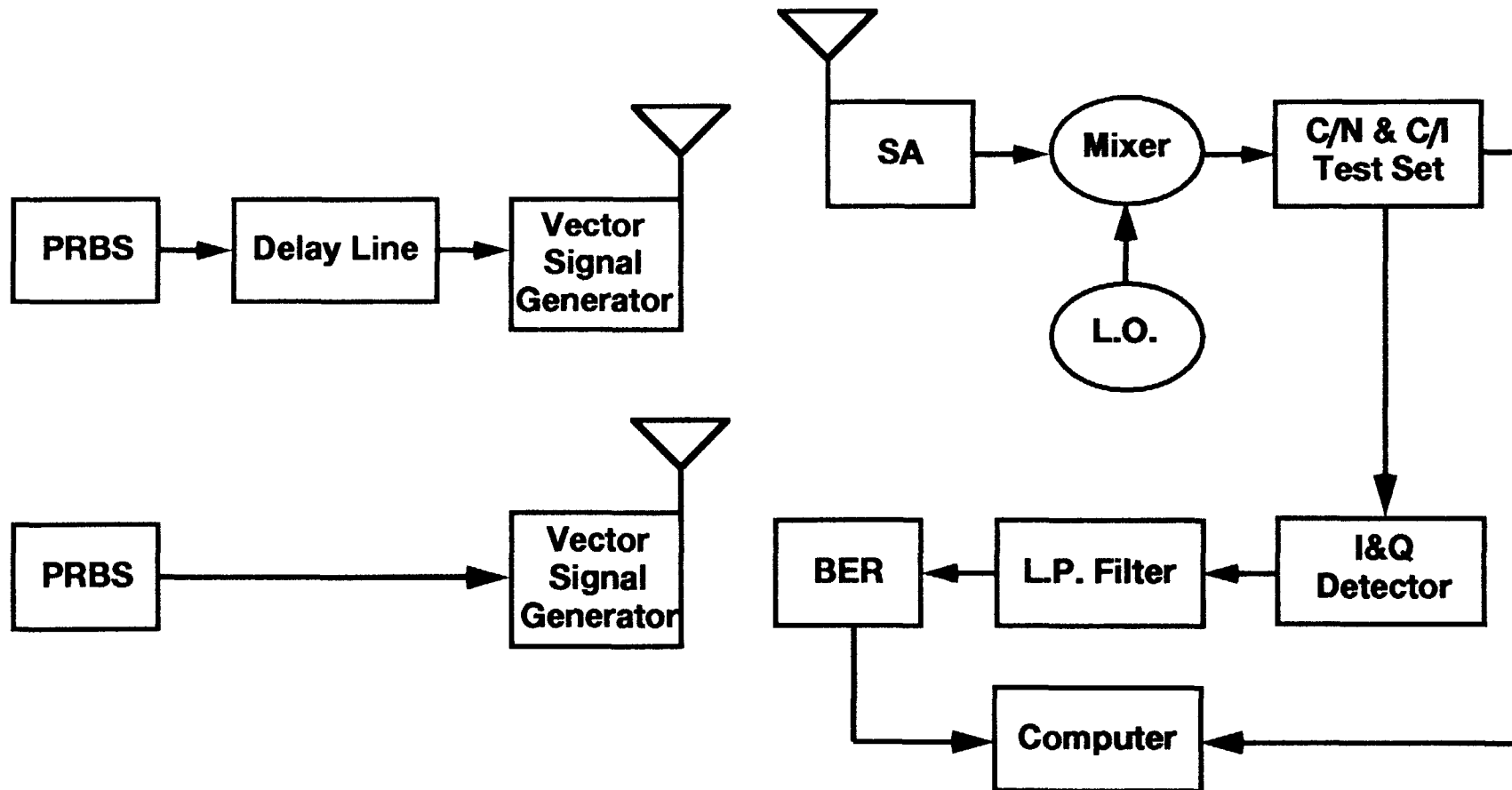
Future Work

- ❑ An investigation of different modulation and coding schemes.
 - ❑ Additional measurements in a suburban location.
 - ❑ Additional measurements investigating the effect of relative frequency offset.
 - ❑ Combining field trial results and prediction tools to identify simulcast problem areas and their respective size as a function of data rate.
-

Modulation Schemes

- ❑ The simulcast environment provides a fundamental limitation on the over-the-air data rate - 3.2kb/s, possibly 4.8 kb/s (? to be tested)
 - ❑ Investigation of multi-level modulation schemes to increase effective data rate:
 - Multi-frequency FSK
 - Multi-level FSKextending effective data rate from 6.4, 9.6 kb/s
 - ❑ More complex scheme possible with the latest technologies:
 - 16QAM offering 19.2 kb/s
 - SS/CDMA
 - ❑ Constraints:
 - Size, cost and power consumption of pager
 - Adjacent channel interference
 - Power amplifier technology
 - Control Equipment
 - System Cost
-

Modulation Schemes Test Hardware

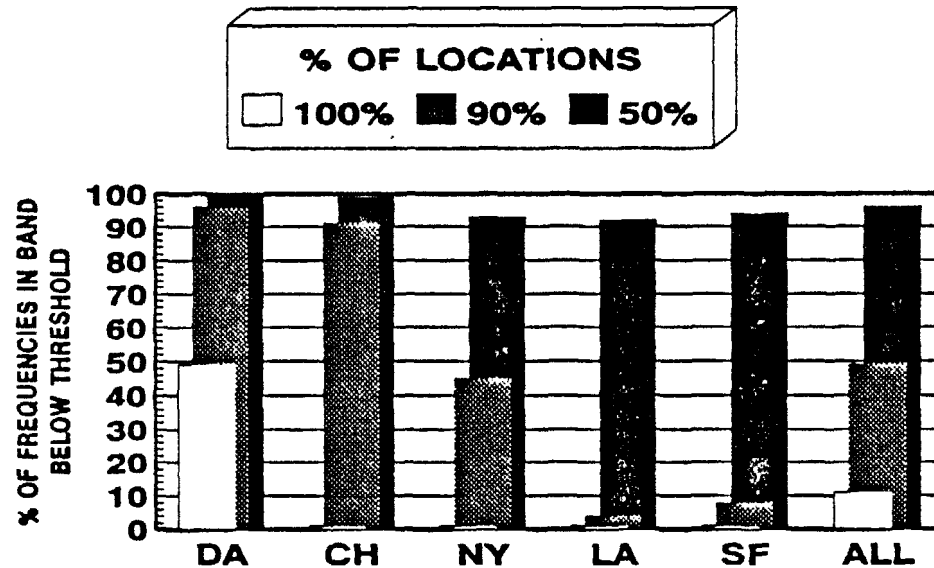


Spectrum Usage Measurements

- ❑ Objectives: determine the relative degree of current spectrum usage
 - ❑ Methodology:
 - Five cities, New York, Chicago, Dallas, San Francisco and Los Angeles
 - 14 frequency bands from 600 to 2,500 MHz
 - 37 geographic locations were chosen on a square grid about the center of each city
 - Measurement locations were selected at the intersection points of the grid - 5 mile spacing
 - Measurement were made from small receiving van
 - Measurements at each site lasted 30 minutes - not long enough to develop temporal statistics but provided good statistics of the geographical variability
 - Receiving parameters : 10 kHz bandwidth, 3kHz video filter, sampling detector
 - ❑ Other considerations:
 - Spectrum Usage depends on receiver bandwidth
 - No account has been made for existing receivers
 - Signal levels are measured with a vertically polarized antenna
-

GPMRS Spectrum Usage Results

□ Threshold = -115 dBm

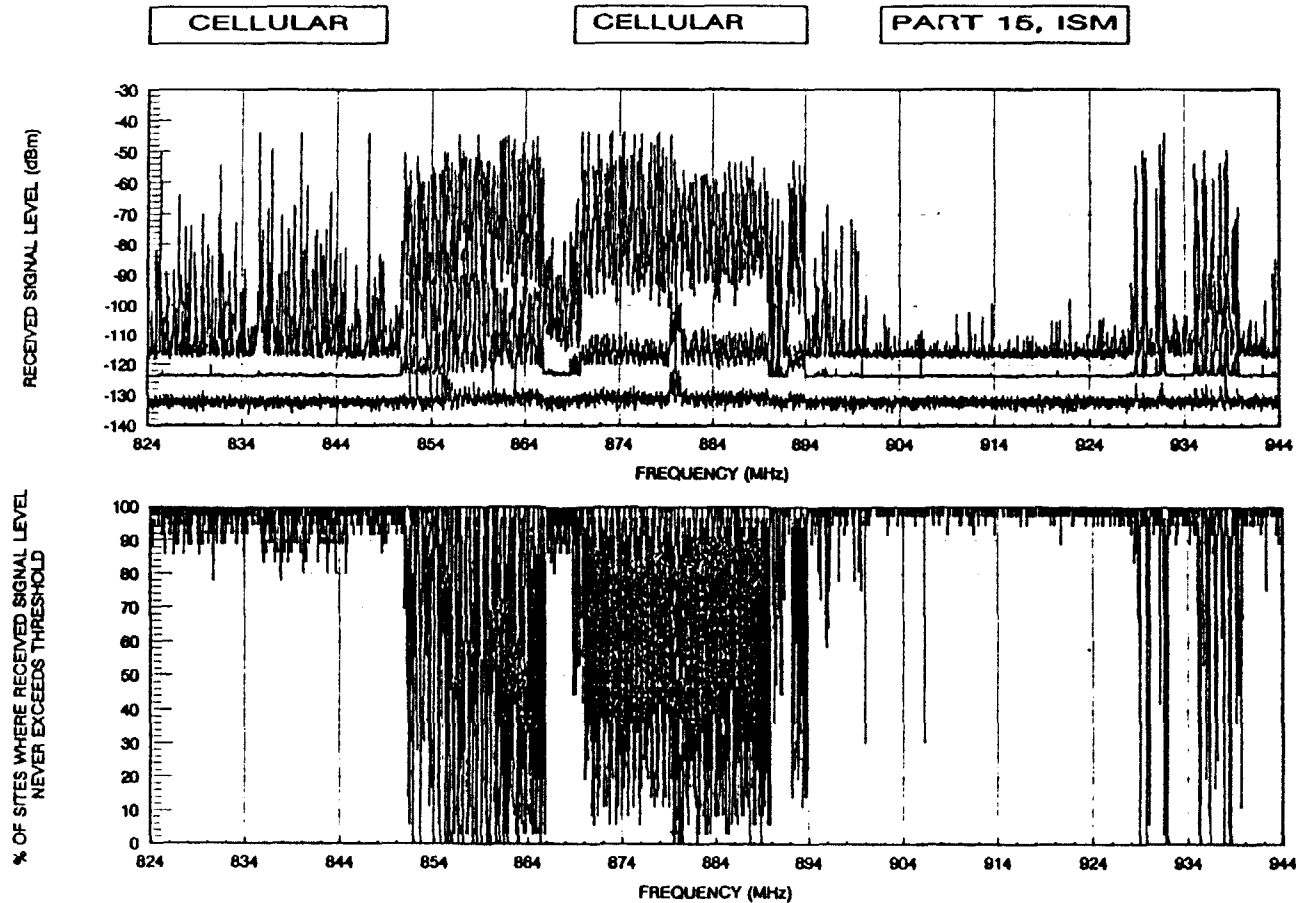


Measured band usage for all cities, 930-931 MHz

□ Example:

The 50% number is the percentage of the band unused at the typical (median) site (i.e. percentage of band unused at the busiest site after the busiest 50% of the sites have been discarded)

GPMRS Spectrum Usage Results



Signal level (top) and measured frequency usage
(bottom) plots for Dallas 824 - 944 MHz

GPMRS Spectrum Usage Summary

- ❑ 930 - 931 MHz band show noticeable usage
 - Observations from the measurements show significant transmitter noise sidebands of the adjacent paging bands or intermodulation distortion from the measurement system in all cities except Dallas
 - Measurements indicate importance of maintaining sufficient adjacent channel interference (i.e. no sidebands). Coordinating two-way paging with many providers within 1 MHz @ 900 MHz may not be feasible
-

ATTACHMENT 5

ADVANCE PAGING MODULATION TEST PLAN

for improving Data rates of paging
systems in a simulcast environment

EXECUTIVE SUMMARY

The purpose of Phase 2 Tests will be to continue the efforts begun in Phase 1 by investigating advanced modulation schemes for increasing the effective data rate of paging systems in a simulcast radio environment.

The maximum baud rate achievable when one information bit is transmitted during the time of one signalling bit is 4800 baud.

Advanced modulation schemes increase the effective data rate by transmitting more than one information bit during the time interval of one signalling bit.

Modulation schemes to be investigated are 4 Level BFSK, Multi-tone FSK, QPSK and QAM.

Since commercial radio equipment is not available for these tests our work will initially be confined to the laboratory environment.

Test equipment that is readily available for working with the more advanced digital modulation schemes will be used to simulate the simulcast paging environment.

The results of the tests will be presented in graphs that will demonstrate the ability of each modulation scheme to perform in a simulcast radio environment.

Table of Contents

Definition of terms.....	Section 1.0.....	3
Introduction.....	Section 2.0.....	4
Test Definition.....	Section 3.0.....	5
Test System.....	Section 4.0.....	6
General Description.....	Section 4.1.....	6
Transmitter.....	Section 4.1.1.....	7
Receiver.....	Section 4.1.2.....	7
Test Equipment List.....	Section 4.2.....	7
Test Equipment Calibration..	Section 5.0.....	8
Equipment Setup.....	Section 5.1.....	8
Equipment Calibration.....	Section 5.2.....	8
System Calibration.....	Section 5.3.....	9
Tests.....	Section 6.0.....	9
Results.....	Section 7.0.....	9
Presentation.....	Section 7.1.....	10
Timeline.....	Section 8.0.....	10

1. General terms used throughout document.

BER	:	Bit Error Rate
BFSK	:	Binary Frequency Shift Keying
DPSK	:	Differential Phase Shift Keying
FSK	:	Frequency Shift Keying
GPS	:	Global Positioning Satellite
PRBS	:	Pseudo Random Binary Sequence
QPSK	:	Quadrature Phase Shift Keying
SA	:	Spectrum Analyzer
UTC	:	Universal Time Coordinate.
VSG	:	Vector Signal Generator
VMA	:	Vector Modulation Analyzer
8PSK	:	8 Phase Shift Keying
16QAM	:	16 Quadrature Amplitude Modulation
64QAM	:	64 Quadrature Amplitude Modulation

Advanced Modulation Paging Simulcast Test Plan

2. Introduction

Results of Phase 1 tests indicate that in a simulcast radio environment increases in data speed must be accomplished by some means other than simply using a higher transmit data rate.

In a simulcast radio environment intersymbol distortion becomes the determining factor as to the rate data can be sent over a radio link. Propagation delays between the transmit carriers must be kept to within approximately $1/4$ the length (time) of a signaling bit period in order to successfully decode a binary bit stream at the receiver.

In a pure binary shift keying scheme as the data rate increases the bit period duration becomes less. At 1200 baud the bit period is 833 us. At 12.4 Kbaud the bit period is 83.3 us.

As can be seen, the higher the data rate the more critical phase delays become. In a simulcast radio environment the upper theoretical limit of the signaling rate is 4800 baud.

In order to achieve the data rates needed to support advanced paging networks capable of delivering large quantities of data to its customers, an investigation of advanced modulation schemes such as 4 Level BFSK, Multi-tone on-off keying (MOOK) and digital modulation schemes such as QAM and QPSK needs to be conducted.

In discussing data transfer rates the terms baud rate and bits per second have been commonly used to mean the same thing. As long as the signaling bit period of a binary data stream corresponds to one information bit, then baud rate and bit per second rate are equal. If however, the information bit rate is changed to correspond to more than one signaling bit then baud rate and bits per second are no longer equal.

For example, if a data stream containing binary data, where the bit period equals one information bit, is 1200, then the baud rate is 1200 baud and the bit rate is 1200 bps. If however the signaling bit period is kept the same but now two information

bits are transmitted in the same interval of the signaling bit period, the baud rate is still 1200 baud, but the bit rate is now 2400 bps. Therefore it is more accurate to think of baud rate as the signaling bit speed or modulation rate.

In order to reduce the destructive effects of intersymbol distortion, the baud rate must be reduced to a point where propagation anomalies no longer effect the data in a simulcast environment somewhere below 4800 baud, and yet increase the bit rate of the information being sent.

It is the purpose of these tests to investigate advanced modulation schemes and their suitability for use in a simulcast paging environment.

3.0 Test Definition

3.1 General Outline

Investigate and evaluate the performance of different digital modulation schemes in a simulcast radio environment.

Type of modulations schemes to be investigated are QPSK, 8PSK, DPSK, 16QAM and 64QAM at baud rates of 600, 1200, 2400, and 4800.

Data bit speeds at 4.8 kBaud.

QPSK: $4.8\text{kBaud} \times 2 = 9.6 \text{ Kbps.}$

8PSK: $4.8\text{kBaud} \times 3 = 14.4 \text{ Kbps.}$

16QAM: $4.8\text{KBaud} \times 4 = 19.2 \text{ Kbps.}$

64QAM: $4.8\text{KBaud} \times 6 = 28.8 \text{ Kbps.}$

Specific items to be investigated.

1. The ideal baud rate per modulation scheme.
2. Is one modulation scheme inherently less susceptible to intersymbol distortion than another in a simulcast environment.
3. Bandwidth requirements for each modulation scheme.

3.2 Study Analysis

Study the feasibility of using Spread Spectrum techniques for Advance Architecture Paging. Study advanced FSK schemes such as, Multi-tone On-Off Keying (MOOK), and Code Orthogonal Frequency Division Multiplex (COFDM).

4. Test System

4.1 General Description

The tests will be conducted using vector signal generators to generate the advance modulation schemes required, since today's paging transmitters are incapable of producing these schemes.

The test receiver will be a spectrum analyzer with a vector modulation analyzer connected to its output to act as a demodulator for the digital modulation scheme under test. A BER test set connected to the output of the VMA will indicate the Bit Error Rate caused by the intersymbol distortion of the simulcast signals of the two vector signal generators.

By imposing a delay in the path of one PRBS signal to its signal generator propagation delays can be simulated.

The data source for the test will be the PRBS generators used in Phase 1.

See Figure 1 for a block diagram of the proposed test configuration.

4.1.1 Transmitter

The transmitter block diagram is shown in Figure 2. The transmitter is an HP 8780A Vector Signal Generator operating on a frequency of 931 Mhz. The Vector signal generator is capable of providing the advanced modulation schemes required by the test. Namely, QPSK, 8PSK, 16QAM and 64QAM.

The baseband data is provided by a pseudo random bit generator which can be set to any of the required data rates under test, i.e 600 baud, etc.

4.1.2 Receiver

The receiver block diagram is shown in Figure 3. The receiver used for the tests will be an HP 8561B spectrum analyzer the same as used previously for the Phase 1 tests. Connected to its output will be a Noise and Interference test set HP 3708A, feeding an HP 8981B Vector Modulation Analyzer which will serve as the receive demodulator. The output of the Vector modulation analyzer will be connected through a low pass filter to the Bit Error Rate test set to indicate the error rate of the intersymbol distortion.

The use of the Noise and Interference test set will be to measure the SNR and C/I required for each signaling bit for a given Bit Error Rate.

4.2 Test Equipment List

Transmitter	Qty	Vendor	Part#	Status
Vector Signal Generator	2	HP	8780A	1 In House 1 Rent
PRBS	2	PacTel		In House